

Reverberation Modeling Workshops

John S. Perkins

Naval Research Laboratory Code 7140

Washington, DC 20375

phone: (202) 767-9037 fax: (202) 404-7732 email: john.perkins@nrl.navy.mil

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LONG-TERM GOALS

Reverberation modeling is a fundamental tool supporting Navy sonar systems. Because of increased interest in littoral operations, requirements for accurate system performance predictions are placing increasing demands on predictions of reverberation. Requirements for better reverberation modeling are coming from both legacy systems employing new tactics and new distributed autonomous systems needing deployment and control strategies. These demands include better physics and statistical characterizations, required by the need to simulate bistatic and multistatic scenarios in complex (range-dependent) and variable environments using sophisticated wideband signals. Theoretical advances, the availability of high performance computers, and rapidly expanding communication bandwidths have made it technically feasible to implement many of the modeling changes necessary to meet the new requirements. The resulting recent progress in basic and applied research makes this a good time to review current capabilities and propose improvements. These improvements, combined with operational Navy requirements, will help define the way ahead for changes to Navy Standard Models. These models are widely used in applications ranging from training to campaign-level modeling. Currently, there are numerous research models that have had very little in the way of verification and validation – nothing comparable to what has been accomplished by way of benchmarking for forward propagation modeling. Finally, on a related topic, a recent report¹ concerning verification and validation (V&V) of geoacoustic inversion techniques noted the lack of a proven method to generate synthetic reverberation data designed to test these inverse techniques on reverberation data.

The current plan is to conduct two Reverberation Modeling Workshops whose overarching goals will be to identify current capabilities and shortfalls and move the state-of-the-art in reverberation modeling forward. The problems of interest are restricted to a frequency range < 10 kHz and will concentrate on shallow water environments. The first workshop was held at the Pickle Research Center in Austin, Texas, in November 2006. The second workshop is scheduled for March 2007.

OBJECTIVES

The overarching goals of these workshops are to identify current capabilities and shortfalls and move the state-of-the-art in reverberation modeling forward. The November 2006 Reverberation Modeling Workshop provided a forum for investigators active in the development of reverberation models to

¹ D. King, D. Knobles, J. Perkins, M. Siderius, “Recommendations for the Geoacoustic Inversion Toolkit”, NRL Memorandum Report NRL/MR/7140--06-8938 (2006).

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14. ABSTRACT Reverberation modeling is a fundamental tool supporting Navy sonar systems. Because of increased interest in littoral operations, requirements for accurate system performance predictions are placing increasing demands on predictions of reverberation. Requirements for better reverberation modeling are coming from both legacy systems employing new tactics and new distributed autonomous systems needing deployment and control strategies. These demands include better physics and statistical characterizations, required by the need to simulate bistatic and multistatic scenarios in complex (range-dependent) and variable environments using sophisticated wideband signals.					
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exchange ideas, describe their algorithms, and identify problems or deficiencies. The specific objectives of this workshop were to:

- (a) **Summarize/compare existing models.** This includes inputs, outputs, theoretical basis, assumptions/limitations, and speed. This information will be supplied by participants and compiled by the organizers. Other features of interest, but not easily quantifiable, are flexibility, graphics, physical insights provided, and automation.
- (b) **Determine where the cutting edge is in reverb modeling.** In order to define the way forward for future developments one needs two things: An assessment of where we are now, and an assessment of what capabilities are lacking. The workshop will concentrate on the former item, but will also address the latter.
- (c) **What is the speed/accuracy of current codes?** This can be viewed as a subset of (b), but is listed separately because it will form a major part of the workshop (see the discussion in the ‘Approach’ section below).
- (d) **Propose an approach to generating synthetic data for use in inverse algorithms.** We expect that, assuming we meet the objectives (a)-(c), this will essentially be a by-product of the workshop.
- (e) **Outline future research directions.** This includes 6.1 through 6.4 research and will assist Program Sponsors in prioritizing investments.

APPROACH

- (a) Participants were asked to submit an abstract for a presentation that detailed the essential features of their reverberation model. They were also asked to submit a paper with a theoretical description of the model, its assumptions, limitations, and performance on the workshop problems (see (b) below). These papers follow a common format and form the basis of the deliverable report listed in the “Results” section below.
- (b) Workshop participants were expected to solve at least one problem from a group of 20 problems. These problems ranged from monostatic range-independent 2D geometries to bistatic range-dependent 3D geometries. The problems were defined by a Problem Definition Committee consisting of seven reverberation modelers. The committee approved these problems using the criteria that (1) the majority of the reverberation modeling community should be able to solve most of these problems, and (2) the problems should highlight the similarities and differences in the ways the models incorporate the relevant physics. The problems were posted on an ftp web site (<ftp://ftp.ccs.nrl.navy.mil/pub/ram/RevModWkshp>) on 1 April 2006. Participants were encouraged to begin working these problems and to submit solutions as soon as possible. This allowed time to correct inadequacies that were discovered in the problem definitions and also allowed a participant to submit a new solution if necessary.

These are NOT blind tests, since, generally, a ground truth solution is not available. The organizers collected the solutions and plotted them for comparison purposes. The problems were designed so that the mutual agreement (or non-agreement) of solutions would teach us

about the strengths/weaknesses of the various models. [This approach is similar to that taken for the first PE workshop² where no ground truth was available. Recent work by Chris Harrison at NURC may provide us with a range of analytical solutions that can be used as rough benchmarks for certain specialized problems.] As noted above, one deliverable for the first workshop will consist of several problems that can serve as benchmark problems for a variety of future efforts in reverberation modeling.

Simply defining these problems was not an easy task. Many models do not have much flexibility in the scattering kernels they employ. This was a contentious issue. For models that cannot treat the exact scattering problem, we also provided loss and scattering strength vs. angle and frequency.

The main point that participants were asked to keep in mind is that these problems were to help stimulate and focus the discussions of the workshop, and did not qualify as benchmarks at the time of the workshop. As stated above, we hope that the workshop participants will be able to agree on several problems that can serve as future benchmarks.

(c) Finally, some time was devoted to defining the objectives for the second workshop.

WORK COMPLETED

A joint memorandum establishing sponsorship of these workshops was signed by the Technical Director, Office of the Oceanographer of the Navy, and the Head of the OBS Department, Office of Naval Research. This memorandum, along with a workshop announcement and call-for-abstracts was distributed by electronic mail to approximately two hundred offices and individuals. This call resulted in a workshop with over forty attendees and where fifteen reverberation models were represented. The co-chairmen of the workshop were Mr. John Perkins (NRL) and Dr. Eric Thorsos (APL/UW). The workshop was conducted at the Pickle Research Center in Austin, Texas. Dr. David Knobles (ARL/UT) served as the local host and point-of-contact.

The Problem Definition Committee (discussed above) was formed and developed the twenty problems that focused the activities and discussions. Dr. Kevin LePage chaired this committee of seven scientists experienced in reverberation modeling. Twenty problems were identified including (1) two- and three-dimensional problems, (2) Lambert's Law problems, (3) problems with both bottom and surface roughness, (4) monostatic and bistatic geometries, and (5) range-independent and range-dependent problems. The Problem Definition Committee will suggest problems to re-visit at the second workshop, including possible modifications or additions.

The workshop problems (and other relevant information) are available at the anonymous ftp web site listed at the top of this document.

The second workshop is scheduled for March 2007, again at the Pickle Research Center in Austin, Texas. The first workshop concentrated on benchmarking monostatic and bistatic reverberation predictions for littoral environments. The second workshop will expand the focus to include system

² James A. Davis, DeWayne White, and Raymond C. Cavanagh, "NORDA Parabolic Equation Workshop, 31 March - 3 April 1981," NORDA Technical Note 143 (September 1982).

characteristics (e.g. large bandwidth), higher-order moments, and sources of clutter. No measured data sets were employed in the first workshop, whereas several data sets are will form the focus of the second workshop. In addition to the Problem Definition Committee, we have formed a Data Definition Committee to identify available data sets to be used in the second workshop. Dr. Roger Gauss is serving as chairman of this committee.

As a consequence of the first workshop, a special session on reverberation modeling is scheduled for the November/December 2007 meeting of the Acoustical Society of America to be held in New Orleans. The co-chairmen of the Reverberation Modeling Workshops (John Perkins and Eric Thorsos) have volunteered to co-chair this special session. This session will consist of a total of 23 papers, 17 of which will address workshop problems to some degree.

RESULTS

The main deliverable from the first workshop will be a technical report/proceedings detailing the characteristics of each of the participating models and a comparison of the solutions received. The workshop co-chairmen, working directly with individual modelers, have identified and resolved numerous minor issues preventing close agreement between solutions. These issues concern normalizations and consistent treatment of scattering. More serious science issues were also raised. Among these are the treatment of reflection loss for the total field and use of the Born approximation. These two issues are not unrelated, but for simplicity we'll discuss them separately.

- The reflection loss issue concerns the (widespread) use of the plane-wave Rayleigh reflection coefficient (for the bottom) and the Modified Eckart loss (for the surface) each time a ray (or mode) interacts with a boundary. In the plot below, we see two families of results with differences of ~30 dB at 10 seconds. The "upper" family of curves used the Rayleigh reflection coefficient and the "lower" set used the supplied coherent loss table corresponding to the given roughness. At first, one might say the latter are "correct", but the true solution at longer ranges requires multiple boundary interactions and the long-range behavior might actually be better approximated using the Rayleigh reflection coefficient. We have independent simulations of forward propagation that suggest this may be correct. This issue was raised prior to the workshop and led problem solvers to use each approach. The "true" answer may lie somewhere in the middle of the two groups, most likely closer to the upper curves for which the Rayleigh reflection coefficient was used. However, the true answer may lie closer to the corresponding lower curves for rougher bottoms or the ocean surface.

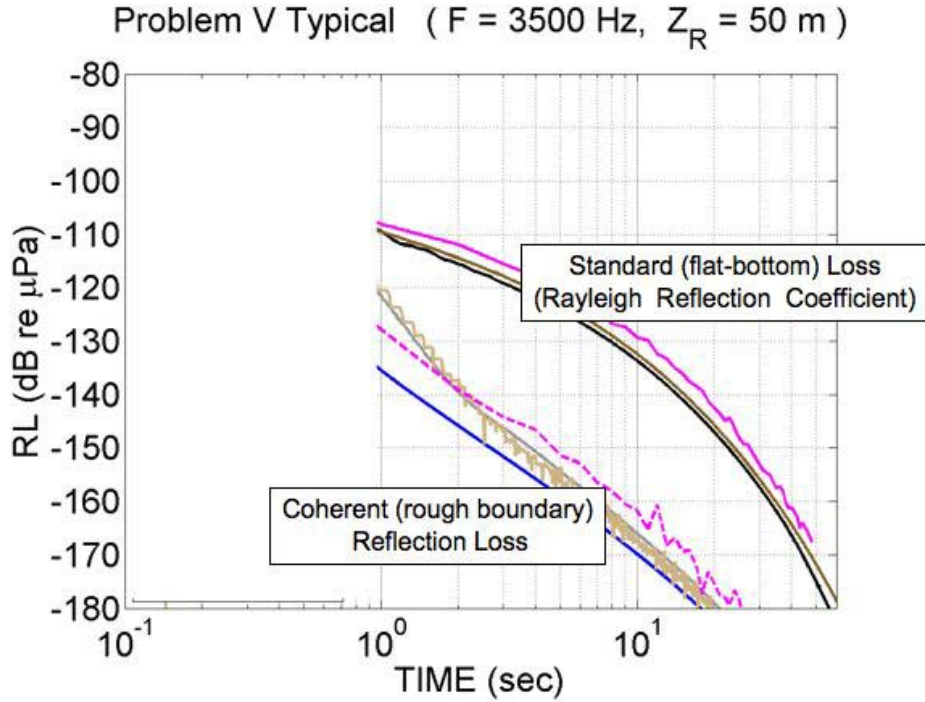


Figure 1: Reverberation levels versus time for workshop problem number five (3500 Hz). The plot shows two families of curves, each corresponding to a different treatment of the reflection loss at the bottom boundary. At ten seconds, these families differ by approximately 30 dB.

- As for the Born approximation issue, this is related to the problem of neglecting multiple scattering. Currently, every (practical) reverberation model (effectively) allows only one scattering event on the trip from source to scattering patch and then on to the receiver. To be totally correct, every time a ray (or mode) interacts with a boundary, it should spawn an entirely new fan of rays that are each weighted by the scattering kernel and traced on in 3D (where they may be scattered again). Since this is very difficult and time consuming, it is important to know when the more practical approach is accurate enough. We expect that there may be mid-frequency/rough surface cases where *single* scattering is not accurate.

We expect that some of the 2D finite-element solutions that have not yet been completed will help resolve these problems. We will also be looking for data sets that might shed light on these, and other, issues.

As an example of a case where we achieved closer agreement, see the plot in Fig. 2 below containing fifteen independent solutions. This was a 3D Lambert's law problem and it was very satisfying to see such agreement at longer times from so many solutions. We believe we can bring these into even closer agreement since the differences seem to indicate normalization inconsistencies. This degree of agreement was accomplished, at least in part, by the pre-workshop collaborations that took place.

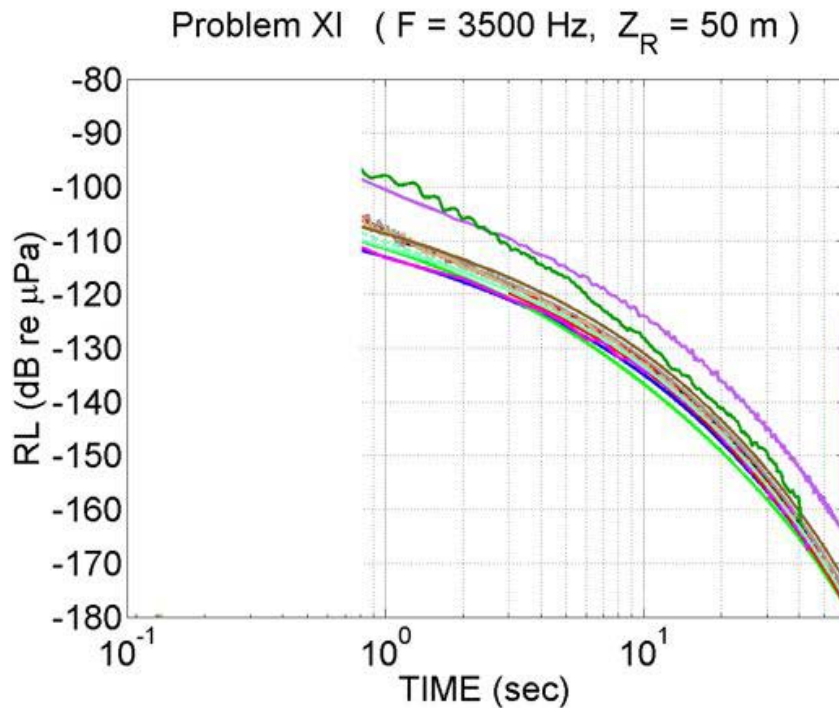


Figure 2: Reverberation levels versus time for workshop problem number eleven. The plot shows fifteen independent solutions to a 3D Lambert's Law problem (3500 Hz). The curves are tightly bunched with twelve of the fifteen solutions lying within a range of three to four dB at ten seconds. The other curves differ due to known (minor) issues.

IMPACT/APPLICATIONS

Please see the discussion under in the **LONG-TERM GOALS** section above.

TRANSITIONS

These workshops are being co-sponsored by PEO C4I&Space (PMW-180). Recommendations for new models or modifications to existing models will be made to PMW-180. Also, inverse algorithms that determine geoacoustic parameters from observed reverberation are also potential transitions to PWM-180.

RELATED PROJECTS

There are numerous projects addressing issues in reverberation modeling. This is reflected in the fact that we expect workshop participation from the following research organizations: Applied Research Laboratory, Pennsylvania State University, Applied Research Laboratories, University of Texas, Applied Physics Laboratory, University of Washington, Naval Research Laboratory, Defence Research and Development Canada, NATO Undersea Research Centre, Applied Physics Laboratory, Johns

Hopkins University, Northeastern University, Science Applications International Corporation and others.

REFERENCES

D. King, D. Knobles, J. Perkins, M. Siderius, “Recommendations for the Geoacoustic Inversion Toolkit”, NRL Memorandum Report NRL/MR/7140--06-8938 (2006).

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